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II - RESEARCH SENSORS

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The Lewis program in research sensors is directed at development of sensors and sensing techniques for research applications on turbine engines and propulsion systems. In general, the sensors are used either to measure the environment at a given location within a turbine engine, or to measure the response of an engine component to the imposed environment. Locations of concern are generally within the gas path and, for the most part, are within the hot section of the engine. Since these sensors are used for research testing as opposed to operational use, a sensor lifetime of the order of 50 hr is considered sufficient. The following discussion will present a sample of this work, describing programs to develop a dynamic gas temperature measuring system, total heat flux sensors, a variety of thin-film sensors, and high-temperature strain measuring systems.

DYNAMIC GAS TEMPERATURE MEASURING SYSTEM

One of the most important parameters in a turbine engine hot section is gas temperature. Normally only time-averaged temperature is measured. Fluctuations in gas temperature are, however, of great concern for hot section durability and combustor modeling activities. The dynamic gas temperature measuring system uses a probe (fig. II-1) with two wire thermocouples of different diameters, typically 75 and 25 μm (0.01 and 0.003 in.). The thermocouple junctions are butt welded and are located midway between the supporting posts. The thermocouples are within 1 mm of each other so that they are measuring essentially the same gas sample. This probe provides dynamic signals with limited frequency response. By comparing these signals over a range of frequencies, a compensation spectrum can be generated sufficient to provide compensated temperature data over an extended frequency range. The target frequency response for this system was 1000 Hz. This is probably higher than necessary for questions of durability loss due to thermal cycling, but if one is interested in modeling combustor processes or the flow in a combustor, 1000 Hz is a reasonable target. The upper limit in achievable frequency response for such a system is determined by the signal-to-noise ratio.

This system has been developed and used to measure fluctuating temperatures in both combustors and engines (refs. II-1 to II-4). Figure II-2 shows dynamic temperature data obtained from a probe at the turbine inlet of a PWA F-100 engine operating at an intermediate power setting and with an average turbine inlet temperature of 925 °C (1700 °F). The plot on the left is the dynamic signal from the 25-μm-diameter (0.003-in.-diam) wire thermocouple with no frequency compensation. The rms value of the temperature fluctuation is 41 °C (74 °F). The plot on the right is the compensated signal from the same

thermocouple. The rms value of the temperature fluctuation is 218 °C (390 °F) and the peak-to-peak fluctuation is over 1000 °C (1800 °F). Such a large temperature fluctuation implies that there are filaments of primary combustion gas and dilution gas within the combustor exhaust stream.

TOTAL HEAT FLUX SENSORS

Another environmental parameter of interest for hot section durability is total heat flux. We have developed miniature total heat flux sensors (refs. II-5 to II-10) which can be welded into combustor liners and built into cooled turbine airfoils. Figure II-3 shows one sensor configuration based on the Gardon gage design as it would be built into an airfoil. In this case, the airfoil must be opened so that the sensor can be installed from the cooled wall side. A cylindrical cavity 1.5 mm in diameter (0.06 in.) is cut in the wall leaving a thin membrane at the hot side surface. ISA type K thermocouple wires are located in the cavity as shown, and then the cavity is filled with ceramic cement. With this sensor, the temperature difference between the center of the membrane and the side wall is a measure of heat flux. This temperature difference is measured with the Alumel-bladewall-Alumel differential thermocouple. The use of the burner liner or airfoil material as part of a differential thermocouple circuit is an innovation that considerably simplifies construction, but it requires calibration of the materials involved. Calibration tests showed that this technique could provide acceptable signals. These miniature heat flux sensors must be calibrated over the temperature range in which they will be used because of the nonstandard differential thermocouple and because of the uncertainty in positioning the thermocouple junctions.

Total heat flux sensors have been used in tests on combustor liners and on turbine airfoils. Figure II-4 shows a segment of a combustor liner which has been instrumented with five total heat flux sensors. The sensors are 7.5-mm-diameter (0.3-in.-diam) disks with thermocouple leads radiating from the edge of the disk. The actual sensor part of the unit is at the center of the disk and is only 1.5 mm (0.06 in.) in diameter. The sensors are individually calibrated and then welded into holes cut in the liner. Tests on combustors such as this one have produced useful heat flux data over a range of combustor operating conditions. Similar sensors built into turbine airfoils have been less successful because of the sensitivity of these sensors to temperature and/or heat flux gradients, which are more prevalent in turbine airfoils.

As noted previously in this section, calibration of total heat flux sensors over the range of temperatures and heat fluxes that will be encountered is a requirement. Figure II-5 shows a photograph of a heat flux sensor calibration system developed at Lewis. The heat source is a 100-kW arc lamp. A reflector is used to focus the energy from the arc onto a ceramic sensor holder. This system can supply a maximum flux of 6 MW/m^2 (500 Btu/ft^2-sec), which is higher than the heat fluxes in present-day turbine engines. The system can operate in both steady-state and transient modes. Two other roughly comparable calibration facilities exist in this country; efforts to cross-compare calibration of test sensors have been started. This is especially important since a national standard for heat flux sensor calibration does not exist for these high levels of heat flux.

THIN-FILM SENSORS

Lewis has been the major advocate and sponsor for development of thin-film sensors for turbine engine applications (refs. II-11 to II-19). Thin-film sensors applicable to turbine engines include temperature sensors, strain gages, and heat flux sensors. Thin-film sensors are formed directly on the component to be instrumented (fig. II-6) by first depositing a suitable insulating film and then depositing sensor and protective films as required. A stable, adherent, pinhole-free insulating film is the base for the whole structure and is the most critical element of the sensor.

An excellent application for thin-film thermocouples is the measurement of the surface temperature of a cooled turbine vane such as shown in figure II-7. The surface of the vane is covered with Al_2O_3 thermally grown from an anticorrosion coating and augmented with sputtered Al_2O_3. Pt and Pt-Rh films are sputter-deposited with thermocouple junctions formed by overlapping the two films at the desired spot. The films extend to the base of the vane where leadwires are connected. Typical thicknesses are 3 µm for the Al_2O_3 and 5 µm for each of the thermocouple alloy films; in this case, no cover film was used. The advantage of this technique over the previous technology, which required swaged thermocouple wires to be buried into grooves cut into the surface, should be obvious.

The present state of the thin-film sensor technology is sufficiently advanced that dynamic strain gages have been used on compressor blades, and thermocouples have been used to measure turbine airfoil surface temperatures in some turbine engine test facilities in the United States. Thin-film, high-temperature static strain gages and thin-film heat flux sensors are still under development. In addition, work is continuing on the basic thin-film sensor technology with the goals of simplifying and improving sensor processing and adapting the presently used techniques to other substrate and sensor materials.

One of our goals is to make the thin-film sensor technology available to the whole U.S. turbine engine community. Impediments to wider usage of this technology are many. One problem is that sensor fabrication is material specific; technology has not been established for a wide variety of materials. Another problem is that the investment required to establish a thin-film sensor fabrication capability is considerable, and commercial services for custom fabrication of thin-film sensors are not yet available.

HIGH-TEMPERATURE STRAIN MEASURING SYSTEMS

The most ambitious goal of the research sensor program is development of 980 °C (1800 °F) strain measuring systems. Approaches being followed in this work include both wire and thin-film resistance strain gages and remote strain measuring systems. The resistance strain gage work involves development of new strain gage materials and extensive testing of available strain gages. Work on remote strain measuring systems has involved three different system concepts based on laser speckle patterns.

A major part of our work in resistance strain gages has been the development of a new palladium-based strain gage alloy (refs. II-20 and II-21). The

outstanding property of this alloy is its repeatability of resistance over the temperature range up to 980 °C (1800 °F). Repeatability of resistance over the temperature range within a few hundred parts per million is a fundamental requirement for a high-temperature strain gage alloy. Work is now underway to develop thin-film and wire strain gage systems using this alloy. Work with other strain gages has involved high-temperature evaluation testing (refs. II-22 to II-24) including a 700 °C (1300 °F) strain gage available from the People's Republic of China.

Resistance strain gages are not the only approach to high-temperature strain measurements. Attractive alternatives are found in a variety of remote optical strain measuring systems, many of which use the laser speckle pattern as a basis for measurements of in-plane surface deformation. We have worked with two laser speckle systems: a photographic system in which speckle pattern photographs are analyzed in an interferometric photocomparator, and an electronic system in which strain is determined from the shift in the speckle pattern falling on a linear photodiode array. This work has included both laboratory development and evaluation in test cell environments (refs. II-23 and II-25 to II-27). A fundamental problem with remote optical systems in test cell environments is interference generated within the viewing path; methods for minimizing or eliminating this problem are being studied.

FUTURE THRUSTS IN RESEARCH SENSORS

Future work in research sensors will be strongly influenced by programs to develop new materials for turbine engines which will permit significantly higher hot section temperatures. These materials are expected to be in the forms of metallic or intermetallic and ceramic matrix composites. The impact of such developments will be twofold. First, these new materials will have markedly different properties compared to the metals involved in the sensors developments already described. The emphasis for surface-mounted sensors will be on thin films, and extensive development of fabrication procedures for these new substrate materials will be required. For remote sensors, there will be requirements to adapt or develop new sensing techniques suitable for these new materials.

The second area of impact is the higher temperatures that will be encountered. Higher temperatures may require new sensor materials and may ultimately require abandonment of surface-mounted sensor techniques. Work is already in progress on development of sensors and sensing techniques for ceramic components for turbine engines. Results of studies on applicable sensor techniques for measurements of surface temperature, strain, and heat flux are available (refs. II-28 and II-29).

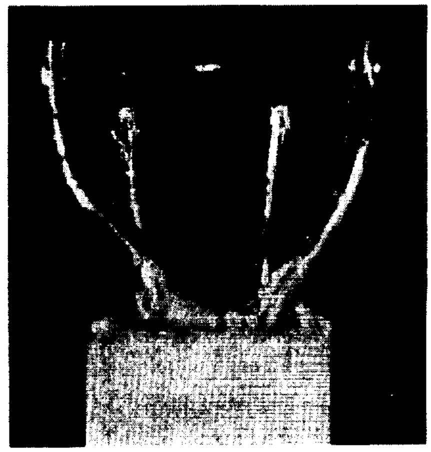

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Figure II-1. - Dynamic gas temperature probe.

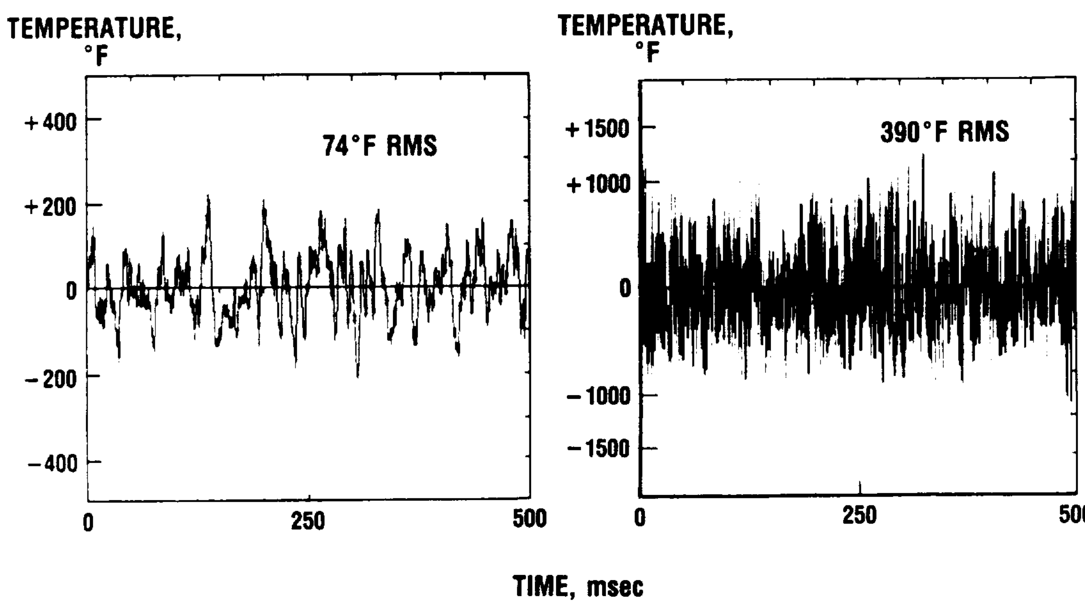

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Figure II-2. - Fluctuating gas temperature measured at turbine inlet of PWA F-100 engine. Left plot shows as-recorded data from 25-μm-diameter (0.003-in.-diam) wire thermocouple with no compensation; right plot shows same data compensated for flat frequency response to 1000 Hz.

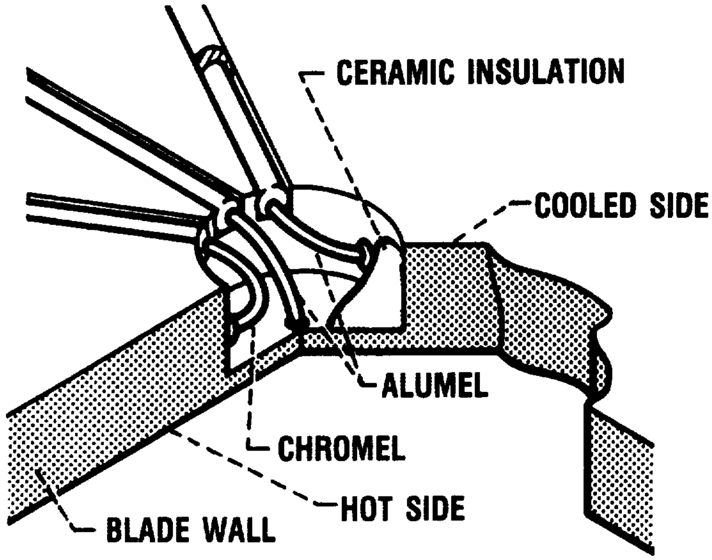

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Figure II-3. - High-temperature heat flux sensor based on Gardon gage design.

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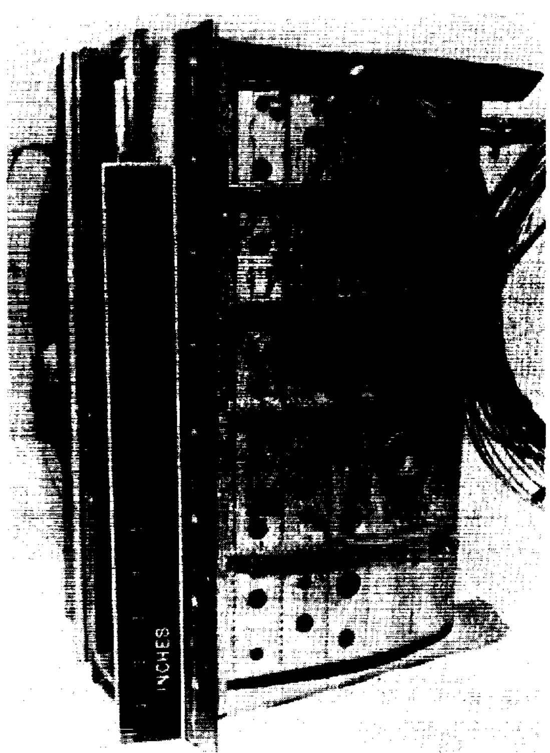

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Figure II-4. - Segment of combustor liner instrumented with heat flux sensors.

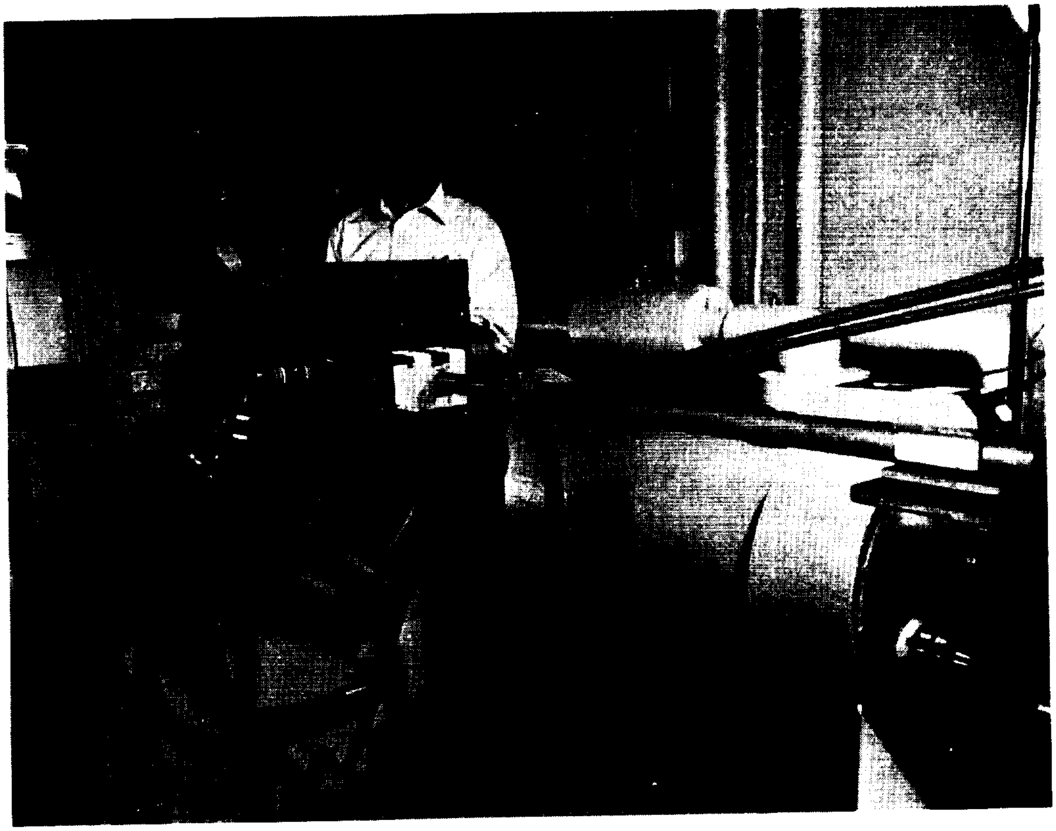

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Figure II-5. - Heat flux sensor calibration system at Lewis Research Center.

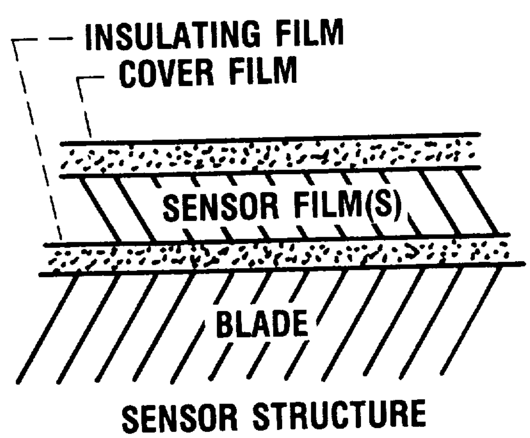

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Figure II-6. - Cross section of thin-film sensor on blade.

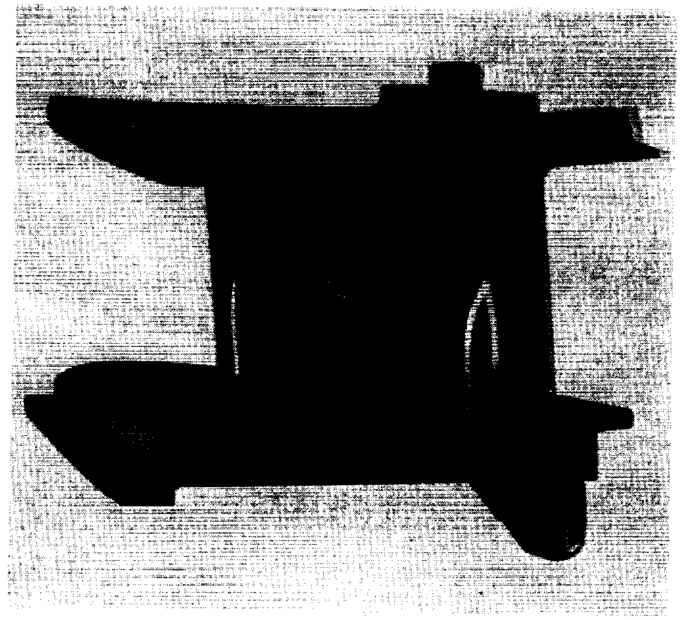

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Figure II-7. - Cooled turbine vane instrumented with four thin-film thermocouples.